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REMARKS

In view of the above amendments and following remarks, reconsideration of the rejections contained in the Office Action of February 27, 2002 is respectfully requested.

FORMAL MATTERS

Regarding the drawings, the Examiner's attention is drawn to the accompanying Notice Re Proposed Drawing Amendments. This notice propose substitution of the current Figures 3A and 3B with photographs corresponding thereto.

A substitute specification accompanies this response in accordance with the requirement made by the Examiner in paragraph 3 on page 2 of the Office Action.

Regarding the rejection of the claims on formal grounds, it is noted that all of the claims have now been canceled. These claims have been replaced with new claims 21-34. Each of these claims has been carefully drafted so as to fully comply with all of the requirements of 35 U.S.C. §112, second paragraph.

REJECTIONS BASED ON PRIOR ART

The Examiner rejected claims 1-20 as being anticipated by Rooks. Furthermore, claims 1, 2, 4-6, 8-10 and 12-20 were rejected as being anticipated by Teraoka, Japanese reference 10-239253. However, it is respectfully submitted that the present invention, at least as now set forth in new claims 21-34, clearly patentably distinguishes over Rooks and Teraoka.

Initially, it is noted that claims 21-34 have been presented as generally corresponding to the original claims. However, the language of the claims has been significantly changed and revised so as to correspond to U.S. practice. No substantive changes have been made for reasons related to patentability, however. Rather, the language has been changed so as to more clearly point out the distinguishing characteristics of the invention.

Thus, in the present invention it has been recognized that, for example noting Fig. 4, in some instances in the prior art, ball grind arrays (BGAs), when being mounted upon a circuit board, sometimes incompletely connect. This condition is difficult to detect from outside of the

mounted BGA, as can be appreciated, for example, from Fig. 2. Prior art techniques have attempted to deal with this problem. However, for various reasons, these prior art techniques are insufficient. These problems are discussed in the background of the present invention.

Thus, the present invention has realized a greater ability to securely detect improper or incorrect connection of BGAs and CSPs, for example, by a new method of X-ray inspection.

Noting for example Fig. 10, the present invention places a sample 13 to be inspected on a stage 14. A planar section of the sample 13a to be inspected has a straight line S, serving as an axis, extending therein. An X-ray source 11 and an X-ray detecting device 12 are positioned and arranged so as to face each other with a sample between them. The X-ray detecting device is swung in translational motion about the straight line while maintaining an incidence plane 12a of the X-ray detecting device parallel to the section of the sample. X-rays are applied to the sample with the X-ray source while rotating the X-ray source about the straight line S in synchronization with the swinging of the X-ray detecting device. Thus, X-rays passing through the sample are detected with the X-ray detecting device.

A control means 17 is operable to control a rotating means 15 and a swinging means 16 for rotating and swinging the X-ray source 11 and X-ray detecting device 12, respectively. The result of detection are processed with an image processing means 18.

The result of taking, for example, a vertical section image along a BGA can be images such as shown by Figs. 5(a) and 5(b). Thus, the device can detect along a line of ball connections 1a, even if such line is not readily visible from the outside of the package, i.e. even if such line is an internal line.

The specification discusses the manner of the operation of the present invention with respect to Figs. 6-9. Noting for example Fig. 9, a point K that is not located in the plane of the section winds up having a relatively obscure image as a result of the method of the present invention. Accordingly, only the desired image results.

Thus, the present invention is primarily defined by a method of X-ray inspection according to claim 21, in which the X-ray detecting device is swung in translational motion about a straight line as an axis. The invention is further defined by independent claim 25, which recites an X-ray

detecting device and a swinging means for swinging the X-ray detecting device in translational motion about a straight line as an axis. The X-ray incidence plane is maintained facing in the same direction, furthermore.

In yet another aspect according to the present invention, instead of translating the X-ray detecting device through an arc about the axis S, for example, a plurality of X-ray detecting devices could be placed along the arc at different positions to provide separate image inputs. This would avoid the necessity for a swinging means 16, for example. This aspect of the present invention is reflected by independent claim 33, reciting a plurality of X-ray detecting devices, wherein the X-ray detecting devices are positioned so as to be able to form a uniform geometric relationship with the X-ray source on the basis of a plane that includes the straight line located at a sample position between the X-ray detecting devices and the X-ray source. Dependent claim 34 further recites that the X-ray detecting devices are positioned along an arc which has the straight line extending through the center thereof.

The cited references to Rooks and Teraoka are simply reflective of the prior art of the present application. Neither of the references discloses nor suggests the present invention. Noting the U.S. patent to Rooks, Rooks discloses a system for obtaining transverse sectional images. As seen in Fig. 6b, the X-ray detector is rotated about a straight line on a vertical plane, with the section as the axis of rotation. By contrast, with the present invention as reflected in each of the independent claims, the X-ray detecting means is swung about a straight line in translational motion. Further, the straight line lies in a plane of the section of the sample, which is clearly not the case with Rooks or Teraoka.

Particularly, as for example as demonstrated by comparing Figs. 11-13, the X-ray detecting device 12 is moved so that the X-ray incidence plane always faces in the same direction. In other words, the motion of the X-ray detecting device is translational, while the source rotates or pivots about the axis S.

The above is reflected in each of the independent claims 21 and 25, as discussed. Such features are clearly neither disclosed nor suggested by either Rooks or Teraoka.

Nor does Rooks or Teraoka disclose a plurality of X-ray detecting device as required by claim 33. More particularly, neither Rooks nor Teraoka discloses or suggests a plurality of X-ray detecting devices positioned along an arc having a straight line extending through the center thereof.

In view of the above, it is respectfully submitted that all of the rejections and objections raised by the Examiner have been overcome, and indication of such is respectfully requested.

In view of the above amendments and remarks, it is submitted that the present application is now in condition for allowance, and the Examiner is requested to pass the case to issue. If the Examiner should have any comments or suggestions to help speed the prosecution of this application, the Examiner is requested to contact Applicant's undersigned representative.

Attached hereto is a marked-up version of the changes made to the specification and abstract by the current Amendment. The attached page is captioned "**Version with Markings to Show Changes Made**".

Respectfully submitted,

Akira TERAOKA

THE COMMISSIONER IS AUTHORIZED TO CHARGE ANY DEFICIENCY IN THE FEES FOR THIS PAPER TO DEPOSIT ACCOUNT NO. 23-0975

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Version with Markings to Show Changes Made

X-RAY INSPECTION METHOD AND APPARATUS USED FOR THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method of X-ray inspection and an apparatus used for the method and, more particularly, to a method of X-ray inspection for inspecting the condition ~~of~~ mounting (connection) of electronic devices such as BGAs (Ball Grid Arrays) and CSPs (Chip Scale Packages) which are ~~further downsized~~ smaller size and have higher densities on boards and the like using X-rays and an apparatus used for the method.

2. Description of the Relevant Art

In recent years, the performance of cellular phones, personal computers, video and audio equipment and the like has been remarkably getting higher. What makes it possible is IC packaging technology, which is at the core of the higher performance ~~thereof~~. The density of packages for mounting IC chips and the speed of signal processing have been getting higher.

In particular, array packages such as BGAs and CSPs, which have recently appeared as a means of enabling an innovative packaging technology, and which are effective in having more terminals, have attracted attention.

However, though the array packages such as BGAs are excellent at having more terminals, it is difficult to judge whether the condition of mounting of an array package on a printed circuit board is good or bad by an optical or a laser visual inspection, since, on account of the construction thereof, the connecting

portion of the package and the printed circuit board is hidden from sight by the package itself when it is mounted on the printed circuit board. In the case of fine-pitch packages, it is difficult to accurately pinpoint the location of defects even by an electrical test.

Fig. 1 is a perspective view diagrammatically showing the state of an example of a BGA 1 seen from the side of terminals. Fig. 2 is a perspective view diagrammatically showing a printed circuit board 2 in a situation where the BGA 1 shown in Fig. 1 is mounted thereon. As is obvious from Fig. 2, it is extremely difficult to judge by their appearances whether the condition of connection of solder balls 1a ~~arranged in the portion~~, except those at for the outermost periphery of the BGA 1 and the printed circuit board 2, is good or bad when ~~in the situation where~~ the BGA 1 is mounted on the printed circuit board 2.

~~At~~ exemplary present, ~~as~~, techniques of inspecting the condition of connection of an array package such as a BGA and a printed circuit board include a system wherein various and precise two- or three-dimensional perspective images of the connecting portion, seen from a given direction, are obtained (radiography), and a system wherein sectional images of the connecting portion ~~looking~~ taken as if it had been sliced on a plane parallel to the main surface of the printed circuit board (so-called transverse sectional images) are obtained (sectional radiography) ~~, are exemplified~~.

~~As an apparatus wherein the~~ radiography ~~is adopted~~ uses, an X-ray three-dimensional inspection apparatus, for example ~~is exemplified~~. Fig. 3 shows examples of X-ray photographs of the connecting portion taken using the X-ray three-dimensional inspection apparatus for radiography.

Fig. 4 ~~is~~ utilizing the X-ray three-dimensional

inspection apparatus, the inner shape, which cannot be observed from the outside, can be observed as perspective images. Therefore, even if the inner shape is complicated, whether the inner condition is good or bad can be judged with a fair precision.

However, it is difficult to precisely detect the open state of terminals (solder balls) which users like to inspect most in the mounting of array packages such as BGAs and CSPs, forming the heart of the latest high-density packaging. Fig. 4 diagrammatically shows an example of the open state of solder balls.

By obtaining transverse sectional (horizontal slice) images of the connecting portion at two or more vertical positions thereof using the sectional radiography, and measuring and comparing the degrees of shadow, the inner shape thereof can be inspected to some extent.

However, it is essentially difficult to precisely detect opens ~~of~~ terminals (solder balls) in the situation where an array package such as a BGA or a CSP is mounted on a printed circuit board through slice-shaped sectional images of transverse sectional images, because it means trying to detect an state which opens appear~~ing~~ in a direction vertical to the main surface of a printed circuit board, from the horizontal direction.

SUMMARY OF THE INVENTION

The present invention was achieved in order to solve the above problems and apparatus for ~~and~~ it is an object of the present invention to provide a method of X-ray inspection whereby the condition of electronic equipment, like the condition ~~of~~ mounting of electronic devices such as BGAs and CSPs, which are steadily getting smaller and reaching ~~having~~

higher densities on boards, and particularly opens ~~of~~ terminals, can be precisely judged ~~and an apparatus used for the method~~.

As described above, hitherto, the connecting portion of an array package, such as a BGA and a printed circuit board, hidden from sight by the package itself, has been inspected using perspective images from horizontal or oblique directions (see Fig. 3) or transverse sectional images. But it is essentially impossible to precisely detect opens ~~of~~ terminals (solder balls) by these inspection systems.

The present inventor noticed that opens ~~of~~ solder balls (see Fig. 4) are problems essentially appearing in a direction vertical to a BGA or the main surface of a printed circuit board, rather than in a direction parallel thereto, and appreciated that the detection of opens ~~of~~ solder balls can be certainly carried out by obtaining sectional images which are vertical to the main surface of a printed circuit board (so-called vertical sectional images), and not by obtaining sectional images which look as if the printed circuit board had been sliced in a direction parallel to the main surface thereof (transverse sectional images) as before. By finding a method whereby ~~the~~ vertical sectional images can be photographed, and developing an apparatus with which the method can be realized, the present invention was completed.

Figs. 5(a) and 5(b) are diagrams showing vertical sectional images of ~~the~~ a connecting portion. Fig. 5(a) shows ~~the~~ a case wherein no defective connection exists, and Fig. 5(b) shows ~~the~~ a case wherein opens ~~of~~ solder balls 1a exist.

A method of X-ray inspection ~~(1)~~ according to the present invention, wherein a section of a sample is photographed using X-rays to be inspected, ~~is characterized by~~ includes arranging an X-ray source to apply X-rays and an X-ray detecting means to detect X-rays facing each other with the sample in between, ~~making~~ an X-ray

incidence plane in the X-ray detecting means parallel to the section, ~~swinging~~ the X-ray detecting means about a straight line on the same plane with the section as the central axis, with the parallel relationship between the X-ray incidence plane and the section maintained, while applying X-rays to the sample from the X-ray source as the X-ray source is rotated about the straight line on the same plane with the section as the axis of rotation in synchronization with the X-ray detecting means, ~~and detecting~~ X-rays passing through the sample in the X-ray detecting means.

In the method of X-ray inspection ~~(1)~~, by mutually moving the X-ray source and the X-ray detecting means ~~as~~ a uniform geometric relationship between them is maintained on the basis of a section of the sample ~~to be a~~ subject, ~~the~~ a section ~~to be~~ a base ~~portion~~ of the movements becomes in a state where it can be regarded as being fixed. On the other hand, the more distant other portions are from the base ~~portion~~ of the movements, the larger the deformation of the images thereof becomes. As a result, the images thereof become obscure, so that they cannot be a subject of visual recognition. Accordingly, a vertical sectional image is successfully obtained.

This principle is described below using diagrams in Figs. 6-8, ~~shown~~ for describing the method of X-ray inspection ~~(1)~~. Figs. 6, 7 and 8 show a plan view, a front view, and a side view, respectively. Fig. 9 is a perspective view diagrammatically showing a sample.

In the figures, reference numeral 13 represents a sample, and the sample 13 is placed on a stage 14 (Fig. 7). The diagonally shaded area 13a (Fig. 9) represents a section of the sample 13 to be a subject. Points A, B, D, E and F

the points E, A and F are on the same straight line L_2, and the straight lines L_1 and L_2 intersect at right angles. A point K in the sample 13 is not on the section 13a but is located at a distance m from the point B on the section 13a.

An X-ray source 11 and an X-ray detecting means 12 are arranged so as to face each other with the sample 13 in between. X-rays are emitted from the X-ray source 11 and X-rays passing through the sample 13 are detected in the X-ray detecting means 12.

(A) By making an X-ray incidence plane 12a in the X-ray detecting means 12 parallel to the section 13a in the sample 13, the points A, B, D, E and F on the section 13a are projected at points a, b, d, e and f on the X-ray incidence plane 12a in the X-ray detecting means 12 located at H (Figs. 6-8), respectively. Here, the point a is the center of the X-ray incidence plane 12a.

(B) The X-ray detecting means 12 is swung or orbited about the straight line L_1 as ~~the~~ a central axis with the parallel relationship between the X-ray incidence plane 12a and the section 13a maintained, ~~while~~ the X-ray source 11 is rotated or pivoted about the straight line L_1 as the axis of rotation or pivot axis in synchronization with the X-ray detecting means 12. By this operation, the X-ray source 11 moves to g from G, and the X-ray detecting means 12 moves while staying in a position parallel to itself (swings) to h from H.

(C) The points A, B, D, E and F on the section 13a are projected at points a, b, d, e and f on the X-ray incidence plane 12a in the X-ray detecting means 12 located at h, respectively.

As is obvious from Figs. 6 and 7, distances r_1, r_2, r_3 and r_4 between the point a and the points b, d, e and f in the X-ray incidence plane 12a are not changed by the movements (B). The scale of geometric enlargement of each point A,

B, D, E or F on the section 13a to the X-ray incidence plane 12a is uniform, and the below relationship is formed.

The scale of geometric enlargement

= Ga/GA = Gb/GB = Gd/GD = Ge/GE = Gf/GF

= ga/gA = gb/gB = gd/gD = ge/gE = gf/gF

The point K located at a distance m from the section 13a is projected at a point K_H on the X-ray incidence plane 12a located at H, and is projected at a point K_h on the X-ray incidence plane 12a located at h. A gap of a distance r_s is generated between the positions where the point K is projected during the movements (B). As a result, the image becomes obscure. The picture flows and is not fixed.

In the method of X-ray inspection (I), a picture which can be obtained from the X-ray detecting means 12 takes the form of the section 13a including the straight line L_1 and having a parallel relationship with the X-ray incidence plane 12a. In other words, a sectional image of the section 13a including the straight line L_1 which is the axis of rotation of the X-ray source 11 and the central axis of the X-ray detecting means 12 and having a parallel relationship with the X-ray incidence plane 12a can be obtained.

Therefore, when a printed circuit board 2 on which a BGA 1 is mounted (see Fig. 2) is placed on the stage 14 and the condition of mounting of the BGA 1 on the printed circuit board 2 is inspected, a sectional image including the straight line L_1 and having a parallel relationship with the X-ray incidence plane 12a, a so-called vertical sectional image (see Fig. 5) can be obtained. Using this image, the detection of opens of terminals (solder balls) can be certainly carried out, and whether the condition of connection in the connecting portion,

which hidden from sight by the package itself, is good or bad can be precisely judged.

The above-described method of X-ray inspection ~~(1)~~ is most effective in obtaining a vertical sectional image of the printed circuit board 2, considering the movements of the X-ray source 11 and the X-ray detecting means 12, ~~but for example~~, when the condition ~~of~~ connection is inspected, it is also possible to obtain not only a vertical sectional image vertical to the main surface of the printed circuit board 2, but also a sectional image oblique or horizontal to the main surface of the printed circuit board 2 (a transverse sectional image in the horizontal case).

~~A method of X-ray inspection (2) according to the present invention is characterized by~~ a section to be ~~a~~ subject being any section vertical to a stage on which the sample is placed ~~in the method of X-ray inspection (1)~~.

~~In the method of X-ray inspection (2),~~ by choosing a section which is vertical to the stage as ~~a~~ section ~~to be a~~ subject, a vertical sectional image (see Fig. 5) can be obtained.

~~A method of X-ray inspection (3) according to the present invention is characterized by a~~ section ~~to be a~~ subject ~~being~~, any section out of ~~the~~ vertical to ~~a~~ stage on which the sample is placed ~~in the method of X-ray inspection (1)~~.

~~In the method of X-ray inspection (3),~~ by choosing a section out of the vertical to the stage ~~as a section to be a subject~~, a sectional image oblique or

~~In the method of X-ray inspection (4),~~ by setting the straight line ~~to be~~ vertical to the stage, a vertical sectional image can be obtained most effectively.

An X-ray inspection apparatus ~~(1)~~ according to the present invention ~~wherein~~ has an X-ray source ~~to~~ applying X-rays and an X-ray detecting means or device for detecting X-rays ~~are~~ arranged so as to face each other with a sample in between, ~~and~~ X-rays emitted from the X-ray source and passing through the sample are detected ~~in~~ by the X-ray detecting means. ~~is characterized by comprising~~ an X-ray incidence plane ~~in~~ of the X-ray detecting means ~~being~~ is arranged so as to be parallel to a prescribed straight line, a swinging means ~~to~~ swings the X-ray detecting means about the straight line as ~~the~~ a central axis ~~as~~ while the X-ray incidence plane is kept facing in the same direction all the time, ~~and~~ a first rotating means ~~to~~ rotates the X-ray source about the straight line as ~~the~~ an axis of rotation in synchronization with the X-ray detecting means.

~~In the X-ray inspection apparatus (1),~~ the X-ray source and the X-ray detecting means are arranged so as to face each other with the sample ~~to be~~ as a subject in between, the X-ray incidence plane is arranged so as to be parallel to the straight line, the X-ray detecting means is swung about the straight line as ~~the~~ a central axis ~~as~~ while the X-ray incidence plane is kept facing in the same direction all the time, ~~while~~ X-rays are applied to the sample from the X-ray source as the X-ray source is rotated about the straight line as the axis of rotation in synchronization with the X-ray detecting means, and X-rays passing ~~in~~ by the X-ray detecting means

including the straight line and having a parallel relationship with the X-ray incidence plane, the plane ~~to be~~ is a base ~~portion~~ of ~~the~~ movements ~~becomes~~ and is in a state where it can be regarded as being fixed.

Therefore, a section of the sample on the plane ~~to be a~~ that is the base ~~portion of the~~ movements becomes a subject of visual recognition. The more distant the other portions are from the base portion, the larger the deformation of the images thereof becomes. As a result, the images thereof become obscure, so that they cannot be subjects of visual recognition.

A sectional image of a section of the sample including the straight line and having a parallel relationship with the X-ray incidence plane can thus be obtained.

Accordingly, when the condition ~~of~~ mounting of a BGA 1 on a printed circuit board 2 on which the BGA 1 is mounted (see Fig. 2) is inspected, a sectional image of the printed circuit board 2 including the straight line and having a parallel relationship with the X-ray incidence plane can be obtained.

~~An X-ray inspection apparatus (2) according to the present invention is characterized by~~ a subject ~~being a~~ section of the sample is on the same plane with a plane including the straight line, and ~~having~~ has a parallel relationship with the X-ray incidence plane, ~~and~~ the section ~~being~~ can preferably be vertical to a stage on which the sample is placed in the X-ray inspection apparatus ~~(1)~~.

~~Using the X-ray inspection apparatus (2),~~ because ~~since~~ a ~~section to be a~~ subject is any section vertical to the stage, a vertical sectional image (see Fig. 5) can be obtained. Using this resultant image, the detection of opens ~~of~~ solder balls can be certainly carried out, and whether the condition ~~of~~ connection of a package on a printed circuit board, which usually hides inside the package, is good or bad can be precisely judged.

~~An X-ray inspection apparatus (3) according to the present invention is characterized by~~ a subject ~~being a~~ section of the sample lies on the same plane with a plane including the straight line and ~~having~~ maintaining a parallel relationship with the X-ray incidence plane, ~~and the section being~~ can be out of ~~the~~ vertical to ~~a~~ the stage on which the sample is placed in the X-ray inspection apparatus ~~(1)~~.

~~Using the X-ray inspection apparatus (3), since~~ With a section ~~to be a~~ subject being ~~is~~ any section except for ~~sections~~ those vertical to the stage, a sectional image oblique or horizontal to the stage can be obtained. ~~Here,~~ a horizontal sectional image is a transverse sectional image.

~~An X-ray inspection apparatus (4) according to the present invention is characterized by setting~~ the straight line ~~to be~~ that is the central axis and the axis of rotation ~~to be~~ is not vertical to a stage on which the sample is placed in the X-ray inspection apparatus ~~(1) or (2)~~.

~~Using the X-ray inspection apparatus (4), since~~ Because the straight line is vertical to the stage, a vertical sectional image can be obtained most effectively.

~~An X-ray inspection apparatus (5) according to the present invention is characterized by having~~ a sliding mechanism ~~whereby~~ can be provided for the X-ray detecting means ~~is~~ for sliding it in a direction vertical to the X-ray incidence plane ~~in one of the X-ray inspection apparatus (1) - (4)~~.

~~Using the X-ray inspection apparatus (5), since~~ Because the X-ray detecting means can be slided in the direction vertical to the X-ray incidence plane, the [illegible] of the sectional image can be finely controlled

a stage on which the sample is placed ~~in one of the X-ray inspection apparatus (1) (5)~~. can also be provided

~~Using the X-ray inspection apparatus (6),~~ since the stage can be Because two-dimensionally transferred, a desired sectional image can be easily obtained.

~~An X-ray inspection apparatus (7) according to the present invention, wherein an X-ray source to apply X-rays and an X-ray detecting means to detect X-rays are arranged, and X-rays emitted from the X-ray source and passing through the sample are detected in the X-ray detecting means, is characterized by having~~ According to another aspect of the invention,
a second rotating means to rotate the X-ray source about a prescribed straight line as the axis of rotation, is provided a plurality of the X-ray detecting means ~~being~~ are arranged, ~~with and~~ each of the X-ray incidence planes ~~in the X-ray detecting means~~ being ~~arranged in such a~~ position so as to be able to form a uniform geometric relationship with the rotating X-ray source on the basis of a prescribed plane including the straight line. Because

~~Using the X-ray inspection apparatus (7),~~ since each of the X-ray detecting means is ~~arranged in such a~~ positioned so as to be able to form a uniform geometric relationship with the rotating X-ray source on the basis of a prescribed plane including the straight line, the plane, ~~to be~~ as a base ~~portion~~ becomes in a state of movement, is where it can be regarded as being fixed.

Therefore, a section of the sample on the plane ~~to be a~~ base ~~portion~~ can become a subject of visual recognition. The more distant the other portions are from the base ~~portion~~, the larger the deformation of the images thereof becomes. As a result, the images thereof become obscure, so that they cannot be subjects of

Accordingly, when the condition of mounting of a BGA on a printed circuit board on which the BGA is mounted (see Fig. 2) is inspected, a sectional image with respect to a prescribed plane including the straight line, which includes the printed circuit board and the BGA, can be obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view ~~diagrammatically showing the state~~ of ~~an example of~~ a BGA seen from the side of terminals;

Fig. 2 is a perspective view ~~diagrammatically~~ showing a printed circuit board in a situation where a BGA is mounted thereon;

Figs. 3(a) and 3(b) are X-ray photographs of ~~the~~ a connecting portion of a BGA and a printed circuit board;

Fig. 4 is a diagram showing ~~the~~ an open state of solder balls;

Figs. 5(a) and 5(b) are diagrams showing vertical sectional images of ~~the~~ a connecting portion of a BGA and a printed circuit board;

Fig. 6 is a ~~diagrammatic~~ plan view ~~shown for a description of~~ illustrating a method of X-ray inspection according to the present invention;

Fig. 7 is a ~~diagrammatic~~ front view ~~shown for a description of~~ illustrating the a method of X-ray inspection according to the present invention;

Fig. 8 is a ~~diagrammatic~~ side view shown ~~for a description of a~~ illustrating the method of X-ray inspection according to the present invention;

Fig. 9 is a perspective ~~view~~ diagram ~~atically showing~~ of a sample;

Fig. 10 is a schematic illustration showing the principal part of an X-ray inspection apparatus according to an embodiment (1) of the present invention;

Fig. 11 is a diagram showing the state of movements of an X-ray source and an X-ray detecting means;

Fig. 12 is a diagram showing the state of movements of an X-ray source and an X-ray detecting means;

Fig. 13 is a diagram showing the state of movements of an X-ray source and an X-ray detecting means; and

Fig. 14 is a side view partly in section ~~diagrammatically~~ showing the principal part of an X-ray inspection apparatus according to an Example 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

~~The~~ preferred embodiments of an X-ray inspection apparatus according to the present invention are described below by reference to the Figures of the drawings.

Fig. 10 is a schematic illustration showing ~~the~~ principal part of an X-ray inspection apparatus according to an embodiment ~~(1)~~. In the figure, reference numeral 13 represents a sample, and the sample 13 is placed on a stage 14. Here, in Fig. 10, a direction vertical to the mount surface of the stage 14 is a Z direction, and two directions vertical to the Z direction are X and Y directions. The stage 14 comprises an X-Y table which transmits X-rays, and can be transferred in the X or Y direction by a stage transfer means (not shown) arranged thereunder. Thus, by arranging the stage transfer means under the stage 14, even a sample having a large area such as a mounted board does not interfere with the inspection thereof.

An X-ray source 11 and an X-ray detecting means 12 are arranged so as to face each other with the stage 14 between them in the vertical direction (Z

direction). X-rays are emitted from the X-ray source 11, and X-rays passing through the sample 13 are detected in the X-ray detecting means 12.

~~Here, as~~ the X-ray source 11 is a microfocus X-ray source of a hermetic tube type having a focus size of 7 μm or so and an outgoing angle of 40 ° or so ~~is used~~. By realizing a minute X-ray focus, a distinct picture can be obtained even if the imaged picture is enlarged.

The X-ray detecting means 12 is arranged so that an X-ray incidence plane 12a thereof ~~in becomes~~ is parallel to an axis S going in the direction vertical to the stage 14 (Z direction). The X-ray detecting means 12 is connected to a swinging means or device 16. It ~~and~~ swings in the direction shown by an arrow M about the axis S as the central axis in response to the operation of the swinging means 16 and with the X-ray incidence plane 12a ~~therein~~ facing in the same direction all of the time.

The X-ray source 11 is connected to a rotating means 15. It ~~and~~ rotates in the direction shown by an arrow N in synchronization with the X-ray detecting means 12 about the axis S as the axis of rotation in response to the operation of the rotating means 15. ~~Here,~~ the operations of the rotating means 15 and swinging means 16 with respect to the X and Y directions are controlled ~~under the control of~~ by a control means 17 storing a transfer program.

The state of movements of the X-ray source 11, which rotates about the axis S as the axis of rotation, and the X-ray detecting means 12, which swings about the axis S as ~~the~~ a central axis, is described below using diagrams in Figs. 11-13. In the figures, reference numeral 11a represents an X-ray focus of the X-ray source 11. Fig. 11 shows a state at the time of start of ~~the~~ movements, while Fig. 13 shows a state at the time of stop of ~~the~~ movements.

As shown in Figs. 11-13, when the X-ray focus 11a (X-ray source 11) and the

X-ray detecting means 12 are moved in synchronization with each other with a uniform geometric relationship maintained, a section 13a of the sample 13 including the axis S, and having a parallel relationship with the X-ray incidence plane 12a, ~~become~~ is in a state where it can be regarded as being fixed. The details are described in the SUMMARY OF THE INVENTION.

The X-ray detecting means 12 is connected to an image processing means 18 (Fig. 10), to which image data (picture signals) corresponding to the detected X-rays are outputted.

The image processing means 18 starts image integrating processing at the same time as the start of the movements, and performs the integrating processing a predetermined number of times (e.g. 256 times) by the time ~~stop of the~~ movements is stopped so as to improve the image quality so that a processed image (static image) is displayed on a monitor 19. The processed image represents a sectional image on the section 13a of the sample 13 as described above.

In the X-ray inspection apparatus according to the embodiment ~~(1)~~, the X-ray source 11 and the X-ray detecting means 12 are arranged so as to face each other with the sample 13 ~~to be~~ as a subject there between, and the X-ray incidence plane 12a is arranged so as to be parallel to the axis S ~~going~~ extending in a direction vertical to the stage 14. The X-ray detecting means 12 is swung about the axis S as the central axis, with the X-ray incidence plane 12a therein facing in the same direction all of the time, while the X-ray source 11 irradiates the sample 13 with X-rays ~~as~~ which being rotated about the axis S as the axis of rotation in synchronization with the X-ray detecting means 12. X-rays passing through the sample 13 are detected in the X-ray detecting means 12.

As described above, when the X-ray source 11 and the X-ray detecting means

12 are moved mutually with a uniform geometric relationship maintained, the section 13a, ~~to be~~ a base ~~portion~~ of the movements, ~~becomes~~ in a state where it can be regarded as being fixed. The more distant the other portions are from the base ~~portion~~ of the movements, the larger the deformation of the images thereof becomes. As a result, the images thereof become obscure so that they cannot be subjects of visual recognition.

Consequently, a sectional image of the section 13a including the axis S, which is the axis of rotation of the X-ray source 11 and the central axis of the X-ray detecting means 12 and ha~~ving~~ a parallel relationship with the X-ray incidence plane 12a, can be obtained.

Therefore, when a printed circuit board 2 ~~in a situation where~~ a BGA 1 ~~is~~ mounted thereon (see Fig. 2) is placed on a stage 14 and the ~~condition of~~ mounting of the BGA 1 on the printed circuit board 2 is inspected, a vertical sectional image (see Fig. 5) including ~~an~~ axis S and having a parallel relationship with ~~an~~ X-ray incidence plane 12a can be obtained. Using this, the detection of opens of solder balls 1a can be certainly carried out, and whether the condition ~~of~~ connection of the connecting portion ~~which~~ is usually hidden from sight by the package itself ~~in the~~ outside observation is good or bad can be precisely judged.

When only simple image improv~~ing~~ processing is performed in the image processing means 18, without processing ~~for~~ obtain~~ing~~ a sectional image, it also becomes possible to observe a perspective image of a sample 13, seen from an oblique direction (see Fig. 3), using the X-ray inspection apparatus shown in Fig. 10.

~~Accordingly,~~ when the image improv~~ing~~ processing is performed in the

inspection of the condition ~~of~~ mounting of an electronic device on a printed circuit board 2, the observation of a perspective image oblique to the main surface of the printed circuit board 2 makes it possible to ~~previously~~ first find likely places ~~to include~~ where defectives ~~to some extent~~ connections might occur. Then, the observation using a vertical sectional image is only needed to be conducted in the likely places. As a result, ~~the~~ inspection efficiency can be greatly enhanced.

In the X-ray inspection apparatus according to the embodiment ~~(1)~~, the axis S is set in a direction vertical to the stage 14, but in another embodiment, it is also possible to set the axis S in any direction (oblique or horizontal) to the stage 14 ~~except for~~ other than the vertical direction ~~thereto~~.

For example, when the X-ray incidence plane 12a is arranged so as to be parallel to the axis S ~~going~~ extending in a direction oblique to the stage 14, the X-ray detecting means 12 is swung about the axis S as the central axis with the X-ray incidence plane 12a ~~therein~~ facing in the same direction all the time, ~~while~~ and the X-ray source 11 irradiates the sample 13 with X-rays while being rotated about the axis S as the axis of rotation, ~~and~~ X-rays passing through the sample 13 are detected in the X-ray detecting means 12, and a sectional image with respect to a plane inclined to the vertical direction can be obtained.

When the axis S is set on the same plane ~~with~~ as the surface of the stage 14, a sectional image (transverse sectional image) of a section on which the sample 13 is sliced horizontally can be obtained.

In the above-described X-ray inspection apparatus ~~according to the embodiment (1)~~, the X-ray detecting means 12 is swung about the axis S as the central axis with the X-ray incidence plane 12a therein facing in the same direction all of the time (the X-ray detecting means 12 swings as shown in Figs.

11-13), and while the X-ray source 11 irradiates the sample 13 with X-rays while being rotated about the axis S as the axis of rotation, and X-rays passing through the sample 13 are detected in the X-ray detecting means 12. But it is also possible to obtain a desired sectional image similarly without transferring the X-ray detecting means 12, by even when an X-ray detecting means 12 being is not swung, but located in each position shown in Figs. 11-13, for example, so that image data are obtained from the plural fixed X-ray detecting means 12.

EXAMPLES

Fig. 14 is a side view partly in section schematically ~~diagrammatically~~ showing ~~the~~ a principal part of an X-ray inspection apparatus according to Example 1. Here, as an X-ray source 11, a microfocus of a hermetic tube type having an X-ray tube voltage of 100 kV, a focus size of 7 μm, an outgoing angle of 40°, and a distance α between its cabinet and its X-ray focus 11a of 9.5 mm is used.

As an X-ray detecting means 12, an image intensifier having high resolution, high contrast, and low noise is used.

A sliding mechanism (not shown) whereby the X-ray source 11 can be slided ~~to~~ in the direction shown by an arrow W_1 is connected to the X-ray source 11. Using the sliding mechanism, the size of an obtained image can be regulated. For example, when the X-ray source 11 is made close to a sample 13, the scale of geometric enlargement increased ~~upped~~, so that the obtained image can be made larger.

A sliding mechanism (not shown) whereby the X-ray detecting means 12 can be slided ~~to~~ in the direction shown by an arrow W_2 is connected to the X-ray detecting means 12. Using the sliding mechanism, the limits of the obtained image can be

finely regulated. For example, when the X-ray detecting means 12 is made close to the axis S, a sectional image of a section 13a of the sample 13 whose upper portion is cut can be obtained.

By placing a printed circuit board 2 on which a BGA 1 is mounted (see Fig. 2) as a sample 13 on a stage 14, a vertical sectional image (see Fig. 5) can be obtained. Using this, the detection of opens of solder balls 1a can be certainly carried out, and whether the condition ~~of~~ connection of the connecting portion, which is usually hidden from sight by the package itself ~~in the~~ outside observation is good or bad can be precisely judged.

Since the microfocus of a hermetic tube type has an outgoing angle of 40°, the X-ray source 11 is tilted so that X-rays emitted from the X-ray source 11 enter an X-ray incidence plane 12a in the X-ray detecting means 12. When the X-ray source 11 is tilted, the distance between the X-ray focus 11a and the sample 13 becomes longer. The scale of geometric enlargement becomes a little smaller than that in the case where the X-ray focus 11a is brought into intimate contact with the sample 13, but it causes no special problem for industrial use.

When the microfocus is not of a hermetic tube type but of an open tube type, a microfocus having a focus size of 2 μm, an outgoing angle of 120°, and a distance between its cabinet and its X-ray focus of 1 mm can be realized. When it is adopted ~~in~~ the X-ray source 11, the X-ray source 11 ~~is~~ does not needed to be tilted, and the distance between its cabinet and its X-ray focus is nearly 10 times shorter than that of the microfocus of a hermetic tube type, so that the scale of enlargement can be extensively improved.

ABSTRACT OF THE DISCLOSURE

~~The present invention was achieved in order to provide a method of~~ X-ray inspection ~~whereby the~~ condition of mounting of electronic devices such as BGAs and CSPs ~~which are~~ steadily getting smaller and having higher densities on circuit boards, particularly open ~~of~~ solder balls and the like, can be precisely judged, ~~and an X-ray inspection apparatus used for the method. The apparatus, wherein~~ an X-ray source ~~to~~ applies X-rays and an X-ray detecting ~~means~~ device to detect X-rays are arranged so as to face each other with a sample there between, ~~and~~ X-rays emitted from the X-ray source ~~and~~ pass~~ing~~ through the sample and are detected in the X-ray detecting ~~means~~ device, ~~comprises~~ an X-ray incidence plane in the X-ray detecting ~~means being~~ device is arranged so as to be parallel to an axis S, a swinging ~~means to~~ device swing the X-ray detecting ~~means~~ device about the axis S as ~~the~~ a central axis, ~~as~~ while the X-ray incidence plane is kept facing in the same direction all the time, ~~and~~ a rotating ~~means to~~ device rotate the X-ray source about the axis S ~~as the axis of rotation~~ in synchronization with the X-ray detecting ~~means~~ device.